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Developing and Fi~~e~~ld Testing Wood

Residue Delivery Systems

Executive Summary

of the Research Project

DEVELOPING AND FIELD TESTING WOOD RESIDUE DELIVERY SYSTEMS

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** Note changes in Tables 26-29 from November 30 version

Abstract

Forest residues have been referenced as a potential energy source, but field efforts to recover residue have been limited. Forest biomass used for energy generally comes from timber stand conversions where conventional harvest methods can be successfully utilized. Residues present different recovery problems than those encountered in stand conversion. The use of conventional logging equipment and methods common to the Intermountain region in the recovery of forest residues is reported here. Recovery operations were conducted on steep and gentle slopes and concurrent with and after logging. Cost of residue delivery on gentle slopes ranged from $5 to $16 per green ton. Costs on steep terrain ranged from $10 to $20 per green ton. Processing and chipping costs ranged from $5 to $12 per green ton.

Introduction

Projections of the cost of forest residue recovery have often been abstracted from the handling times and costs experienced by conventional logging equipment in the recovery of sawlogs. Forest residue presents different handling challenges, however. Material size and shape is highly variable and this makes it difficult to move and consolidate the material. Costs developed directly from sawlog recovery operations may not account for the operational and logistical problems that will be experienced in forest residue recovery.

Although existing logging equipment is not always well suited to the handling of residue, it is usually all that is commonly available. A data base is needed that reflects the differences from normal production encountered when conventional logging equipment works on residue recovery sites. The field experiments and the resulting data should also reflect harvest system modifications that are made to facilitate the flow of residue material.

A series of field experiments of this type were conducted in the Intermountain region of the United States during the summer and fall of 1982. Production rates, system delays, and processing costs were determined. The studies also identified specific physical and logistical problems that must be addressed in residue recovery operations.

The production tests did not cover all the residue and terrain situations that could be encountered but looked at the impact of at least one aspect of most general conditions. These conditions included recovery of slash concurrent with and after logging on slopes above and below 35%. Various sizes and types of processing units were used to reduce the material to a transportable form. Per unit costs were developed from observed production rates and the effective hourly costs shown in Tables 1 and 2. Table 2 shows differences in equipment costs within study sites due to differences in percent effectiveness.

Recovery of Residue From Steep Slopes

Recovery of residue from steep slopes is likely to be the most expensive residue recovery option. Cable logging will be required to move material from the stump to the landing and is generally more expensive than ground skidding. Landing areas for cable operations in the intermountain region are often limited to the area immediately above, below, and on the haul road. This limits the amount and type of equipment that can operate simultaneously at the yarder site and provides no area for the sorting of residue and sawlog material. Landing constraints will generally dictate some type of swing or shuttle system to move material from the yarder to a site suitable for sorting and processing.

Two cable operations were observed during the concurrent recovery of both sawlogs and residue. The systems were studied in both clear-and partial-cuts. The first study area consisted of a 4.9 acre clearcut and

a 4.6 acre shelterwood and utilized a yarder/loader combination called the Kludt yarder. The machine had been built by local logging contractors (Kludt Brothers and Jerry Driver) and consisted of a two drum yarder mounted on the same truck chasis and powered by the same engine as a hydraulic loader. The yarder had a fixed, straight 35 foot tower. The integral loader was used to move material away from the yarding path. Whole trees were skidded to the yarder landing. Sawlogs were bucked to length at the yarder location and loaded on sawlog trucks at the rate of about two loads per day. Residue material within reach of the loader was moved to a point accessible to chip vans at the rate of about six dump truck loads per day. Residue out of reach of the loader was moved to the chipping site after the completion of yarding. A summary of yarder production is presented for the clearcut in Table 3. Production for the shelterwood unit is shown in Table 4. Summaries of productive time and yarding costs are presented in Tables 5 and 6.

Interference of the loader and yarder accounted for 6% of yarder time. Because there were no significant differences in the time required to yard sawlog turns, residue turns, and mixed turns, the cost to yard residue and the cost to yard sawlogs were charged the same cost per piece. The sawlog portion of trees covered the transport cost of any attached residue such as tops.

The sites were located on a haul road that was not negotiable by chip trucks. If the site had allowed it would have been cost effective to have operated the yarder and chipper in sequence. The loader working with the yarder could have fed material directly to the loader mounted on the chipper. Although this would not have utilized all of the chipper capacity, subsequent studies of chipping of residues from stockpiles also showed very low chipper utilization.

Since immediate chipping was not possible, however, and it was necessary to keep the yarder location clear of material, a dump truck modified with high side stakes was employed to haul slash about one mile to a stockpile area accessible to chip vans. The dump truck is an extremely inefficient transport vehicle for wood residue, but is often the only alternative available for long shuttle distances. Material cannot be packed or loaded onto the truck effectively and load capacity is lost because of the non-uniform nature of the residue. Hauling material away from the Kludt yarder accounted for 30% of the total cost of residue and sawlog recovery. Long pieces were often cut so they could be hauled on the short bed of the dump truck. This incurred additional cost in three ways: the cost of making the bucking cuts, the costs of loading extra pieces, and the inefficiencies imposed upon subsequent chipping because the chipper had to handle an increased number of short pieces. The single advantage of the dump truck is that it can easily unload itself.

A combined yarding/chipping operation was estimated to cost $20 per green ton into the chip van in the clearcut and $25 per green ton in the shelterwood. The combined cost of yarding, shuttling material, and chipping from stockpiles was $34 per green ton at an observed chipper productivity of 27%. If the chipper could have achieved 70% productivity, the combined cost would have been $31 per green ton (Johnson and Lee, 1982).

The stands harvested in this area contained a high percentage of sapling sized material. A more efficient method of moving the material away from the yarder would have been to use a standard log truck packed with the whole trees. Material could then have been transported extended distances to a central chipping site. The trees would have been in a form that would have facilitated whole tree chipping. The chipper could have been located at a central merchandizing yard where the chipper and unloading equipment could have been fully utilized.

The second cable study utilized a two-drum Christy yarder and a grapple skidder to shuttle material away from the yarder. An accessible landing was located within 400 feet of the yarding site. Excessive skidder time was required to sort the material into sawlog and residue products at the landing. The landing also had to be expanded to accommodate the accumulation of slash material. Slash piles occupied .18 of the .37 acres available for the landing. Sawlogs were hauled throughout the yarding operation to keep the landing open for shuttle skidding. Excessive decking and sorting time required of the shuttle skidder caused an imbalance between skidding and yarding production. The shuttle yarder was frequently delayed by the accumulation of logs at the yarder. Shuttle skidder time was excessive because of the maneuvering necessary at the limited landing area (Verner, 1983).

Table 7 presents yarder production from the Christy units. Tables 8 and 9 show the breakdown of productive time and costs of yarding and swing skidding from the shelterwood unit. Tables 10 and 11 present this information for the clearcut unit. The yarder was delayed 20% of its total time by decks that interfered with yarding on the clearcut. Table 11 shows the breakdown of time and production for the shuttle skidder on this site. Note that 34% of the skidder time was spent piling slash or sawlogs or waiting for other landing operations such as loading and bucking. The sorting and decking problems experienced in the two cable yarding modules were also important factors in ground skidding studies.

The costs experienced in these two trials are detailed in Table 12. Loading costs for the Kludt modules are included in the yarding cost. Lower piece costs experienced in the Kludt study were primarily a function of a more experienced yarding crew. Costs per unit of weight, however, paralleled the percent slash pieces on a site.

Residue Recovery on Gentle Slopes

Recovery of residues from gentle slopes was investigated concurrent with and after sawlog recovery. Recovery of forest residue after completion of the conventional sawlog harvest may add to the cost of delivering the material to the landing but should reduce sorting and residue storage problems. Even though operations on gentle terrain allow development of larger landings than are feasible on steep slopes, landing capacity can be a problem when land managers restrict their size for environmental and aesthetic reasons.

Experiments with recovery of material after the sawlog harvest involved two systems. At one site a planned slash disposal operation through dozer piling and burning was altered so that material was piled in windrows next to an access road rather than randomly across the site. Material was then skidded from the windrows to a whole tree chipper. Although the chipper maintained one position throughout the study the access road was flat and wide enough to have allowed the chipper to move onto the site. This would have increased moving delays for the chipper but would also have reduced the average skidding distance and time.

Results from this operation are presented in Table 13. Dozer piling production for the residue recovery site did not differ significantly from production observed when slash was piled in the conventional manner. In this instance the cost to pile slash on the recovery site was less than that incurred on the conventional site because the volume of down material was small in the conventional area. An important aspect of building windrows for subsequent recovery is to match windrow size with the grapple capacity of the skidder that will be used to move the slash to the processor. Windrows that are over- or under-sized will cause excess skidder loading time in breaking oversized piles apart or in stopping at more than one under-sized pile for a load.

The results show the effect of skidding distance on skidding and total recovery cost. When skidding distances are long, one skidder cannot adequately supply the chipper and there is excess down time waiting for material. On the observed site the chipper waited for material 43% of the time when skidding distance averaged 446 feet and 7% of the time when the skidding distance averaged 162 feet. Recovery costs into the chip van decreased from $21/green ton with the longer skid distance to $11/green ton with the shorter skid. If dozer piling costs are added to these costs, they increase to $26 per green ton and $16 per green ton respectively.

The tradeoff between chipper move time and skid distance was investigated more fully in an M.S. thesis by Keller (1983). With a 100-foot average skid distance and two 15-minute chipper moves costs on the observed site could have been reduced 19 percent. With 30-minute chipper moves the cost would have been reduced 10 percent. By contrast, use of two skidders at the 446 foot average skid distance would have reduced costs 13 percent (Keller, 1983).

Addition of part of the dozer piling cost may be appropriate where a slash disposal method such as broadcast burning is planned. Where dozing distances are kept to a reasonable maximum (100 feet) dozing for residue recovery does not appear more expensive than normal dozer piling costs. A plot of dozer piling costs with dozing distance showed an optimal dozing distance of about 70 feet on the observed 5-acre sites.

The second operation involved vehicles specifically designed for hauling slash material from the harvest site to a landing. FMC fast track skidders were modified with knuckle boom loaders and dump truck

buckets. Slash was piled on site in a manner similar to that used in dozer piling and was then sorted and loaded into the buckets. A separate loader could load the FMC's faster than they could load themselves and could sort material while the FMC's were traveling to the landing. This insured a relatively clean feedstock at the landing and allowed the firm to meet land owner requirements to leave a certain volume of material on site. The firm, Fuel and Fire Inc., of Portland, Oregon, works on the basis of a total land management contract. They are paid to do site preparation. As part of the site preparation contract they provide a desired amount of site disturbance and recover wood residue in the process. FMC fast track machines lend themselves to this task since they are low ground pressure machines and are known to have relatively low ground impact.

Production rates and costs of residue delivery with these vehicles are shown in Table 14. Total costs including the separate loader are detailed in Table 15. The FMC BG was the larger of the two machines with an 18.5 cubic yard dump bucket and a cpacity of about 6 green tons. The FMC 200 had a 9.5 cubic yard bucket with a capacity of about 3 green tons. The smaller machine was used primarily for slash piling in preparation for loading and skidding. Slash piling by the small FMC allows the loader and larger machine to work with fewer moves. The delivery cost of slash with the large machine is shown in Table 14. Its cost competes favorably with the cost per ton observed for other skidders. When the loader cost is added to skidding cost, it falls within the range of those experienced with dozer piling and a wheeled skidder shuttle to the chipper.

The dump mechanisms and loaders on the units are design advantages that allow them to build clean, orderly decks at the landing. This facilitates subsequent chipping operations. The material is carried above ground and therefore stays cleaner than material dragged behind a skidder. One disadvantage of the machines is that they are single purpose vehicles that are of little value in conventional harvest operations. This forces the owners to keep them busy on site preparation and residue recovery operations. Residue recovery systems that utilize conventional crawlers and skidders have alternative uses for the machines when hog fuel markets or residue conditions are poor.

Recovery of residue concurrent with the sawlog harvest was also studied on two sites. In one instance a grapple skidder was used to deliver sawlogs, slash, and material prebunched from a precommercial thinning and an adjacent clearcut to a central landing with limited area. Delivery costs from the sawlog recovery area for both sawlogs and slash averaged \$0.13 per cubic foot (\$5.20/green ton). Slash comprised 38% of the 27,736 cubic feet of material removed from the 3.4 acre clearcut. A total of 641 separate slash pieces were skidded with a volume of 6779 cubic feet. The remaining 3761 cubic feet of slash travelled free of skidding costs as tops and unmerchantable portions of trees containing sawlogs.

Material was cold decked for later loading and processing. Landing space became very limited as the operation progressed. The skidder spent 9% of its time decking material, 2.5% of its time clearing the landing, and an additional 10.1% of its time moving material from one deck to another at the landing. Productivity of the system could have

been greatly improved if either sawlogs or slash had been processed at the time of skidding (Cordero, 1983).

The second concurrent recovery operation involved a whole tree chipper working in conjunction with a Hahn complete tree delimber. In a normal delimbing operation material is delivered as whole trees to the Hahn. The processor strips the limbs from the tree and bucks logs to selected lengths. The accumulation of nonmerchantable tops and limbs creates a significant landing disposal problem within the system. During the study a chipper processed tops and cull pieces that were left by the Hahn. A Morbark Model 22 was contracted to do the chipping. Although somewhat large for this type operation, the chipper was equipped with a 12-foot feet table and knuckleboom loader. Both of these features were considered important for the chipper at the outset of the study.

Limbs were processed by the chipper for the first third of the study but created infeed and maintenance problems unacceptable to the operator of the chipper. Limbs that were separated from the bole of the tree by the Hahn contained a high proportion of fine dirt and soon dulled the chipper knives. Knife maintenance time decreased from once every 1.4 productive hours when limbs were chipped to once every 3.1 hours when they were disposed of by stockpiling. Tables 16 and 17 illustrate the differences in chipping production when limbs were part of the feedstock and when they were not. Although perceived as a problem by the chipper operator, results show no significant changes in production when limbs were ignored. Cost of knife maintenance decreased when chipping without limbs, however.

The presence of the chipper did not alter the normal mode of operation for the Hahn, but did reduce the time required by skidders to clear the landing and pile slash. Tables 18 and 19 illustrate production results and costs for the Hahn harvester and its supply skidders with and without adjacent chipping. Table 20 shows a detailed breakdown of the elemental times of the Hahn. Table 21 presents this data for the skidders. Using this data a comparison of skidding times with and without adjacent chipping was made and is presented in Table 22. After adjustments for production differences caused by site conditions production of the Hahn was found to be the same with and without chipping. Skidding cycle time was reduced with chipping by .59 minutes per turn because the skidders spent less time performing landing maintenance.

The Hahn harvester can be run with one or two operators. Results for tree processing showed a reduced cost when one operator was used. Integration of a chipper into the operation would require the use of two Hahn operators, however. If the normal mode of operation with a tree processor like the Hahn is to use one operator, then the addition of a chipper would add to the cost of the Hahn system. Table 23 presents a detailed analysis of the elemental costs of the Hahn Harvester with and without adjacent chipping. The table also shows cost differences when one and two operators are used on the Hahn. The Hahn operation observed normally included two Hahn operators and with the two operators the presence of the chipper did not adversely affect normal opera-

tion of the Hahn. Given these observations and the normal mode of tree processing which involved whole tree skidding, the cost of residue recovery does not include the cost of delivery of the material to the landing. This results in the lowest observed residue recovery cost from the Hahn tree processing operation.

Other residue recovery operations needed equipment to deliver material from stockpiles to the chipper or processor. The price paid for using the chipper as an integral part of the tree processing operation was in underutilization of the chipper's capacity. The chipper used in this setting was productive 27% of the time and was delayed waiting for material 32% of the time. Other chippers might have been a better production match with the rate of slash production by the Hahn. Given the difficulty encountered in processing small limbs, a chipper without the 12-foot infeed table would probably have been able to handle the same amount of material as the Model 22. Production of a Trelan Model 14 studied in a salvage operation was a close productive match to the slash production rate of the Hahn. Use of this machine would have reduced capital investment in chipping equipment from $135,000 to $60,000. If the Trelan chipper had been able to handle the slash at 80% productivity, chipping costs would have decreased from $10.34 per green ton to $3.04 per green ton. Utilization of the Trelan's chipping capacity would have been high, but there would have been some pieces too large for the 14-inch capacity of the machine (Dean, 1983).

A principal logistical problem in the use of a chipper in a tree processing system will be a reliable, continuous supply of chip vans. Lack of van capacity will delay both chipping and tree processing operations. Storage area for unprocessed residue between the tree processor and chipper is very limited. Accumulation of residue when the chipper is idle will soon shut down both machines. In the field test of this system, work stoppage of the tree processor was unacceptable to the owner and chips were blown onto the ground when there were no chip vans. This solved the problem of chip van delays, but added a chip loading cost to the total for residue recovery. Chipping delays due to the lack of vans were observed in all whole tree recovery operations where hauling was subcontracted. Where the chipping contractors controlled hauling through their own fleet of trucks and extra chip vans, the problem was minimized.

Costs of chipping on the tree processor site are outlined in the tables developed for all chipping and processing operations observed. With free delivery of the residue to the landing this represents the lowest cost option observed.

Residue Processing

Several chippers, a portable knife hog, and a firewood-type shear were observed processing residues. The whole tree chippers were also observed in their traditional settings to allow comparison of production between chipping whole trees and chipping residue. Table 24 presents the production rates observed on a variety of chippers and processors.

This data is presented on the basis of chip van averages in Table 25. Chipping costs are developed from this data and are presented in Table 26. Tables 27 and 28 present production rates and costs for equipment used to move residue to the processor. This was required in all but the Hahn experiment. In whole tree settings delivery was from the woods; in residue recovery it was from stockpiled residue. In general these costs are as high or higher than the actual cost of processing.

Total costs of chipping and processing including the cost of delivery are presented in Tables 29 and 30. The most significant single delay in all operations was a wait for chip vans. This was followed by delays for the lack of material. Whole tree chippers, as expected, performed better in traditional whole tree operations. Not only was the percent productivity higher, but the chipping rate per productive hour also increased. A productive hour is defined as hours free of delays when the unit is actually chipping material. The difference in rates per productive hour for residue and whole tree chipping reflects a difference in the size of material chipped relative to chipping capacity. Whole tree chipping utilized most of the throat diameter available on the chipper. Residue chipping generally involved smaller, more irregular pieces and the operators could not keep a full load of material in the chipper.

The highly variable size of forest residue presents an engineering problem to designers of residue processors. Most whole tree chippers are designed for horizontal feed of long stems with limbs and tops attached. Once the tree starts through the chipper, the operator can concentrate on loading another tree. It is usually possible to place the butts of the next load of trees on the tops of the trees being chipped so that the material feed is continuous. Chipping of the many short, irregular pieces often found in forest residue does not allow the operator sufficient time to find and load subsequent pieces. There is little opportunity to begin feeding of a second piece before the first is completely chipped. This results in a loss of production time to the loading function.

Hogs that have been modified for portability can handle short, irregular pieces very well, but at low production rates. Problems are also encountered with longer pieces. Most hog type processors feed from the top and long pieces must be bucked or shortened before proces sing. Residue processing requires a machine that can efficiently handle both long and short pieces. The Nicholsen Fuel Wood Processor with its long, wide feed table accomplishes this task fairly well. Its limitations are in its high capital cost and in its requirements for a fairly large landing.

An alternative to complete processing was observed in a shear designed to cut tree pieces from 18- to 48-inches in length. Material was loaded onto a feed conveyor by a separate hydraulic loader. The shear was set to make a cut every 8 to 9 seconds. Sheared material was carried by conveyor to a short wheeled based truck. The hauling vehicles could easily negotiate the tight turns often found on logging roads. The system was originally designed to reduce residue to a uniformly small size that could be easily fed to a hog. The material

found higher value as firewood and is currently being marketed in that form. Table 26 shows that shearing costs were competitive with the costs of whole tree chipping. When loader costs are added to the system (Table 27), however, its cost increases to that of other residue processing alternatives.

Total residue processing costs shown in Table 30 depict a cost range of from $9.65 to $36.77 per green ton for material delivered to the landing, processed, and deposited or blown into long distance delivery vehicles. Hauling costs must be added to these figures. Operation of a residue processing unit in conjunction with a tree processing system that already bears the cost of delivery of all material to the landing is the least cost system. Alternatives that do not involve direct processing must include the cost to move residue from cold decks to the processor. Delivery cost of the residue from the woods to the cold decks must be included for operations that do not normally bring whole trees to the landing. This cost could be partially offset by the funds usually spent for slash disposal, however.

Summary

Residue recovery is currently possible at costs that in some instances will be totally recovered by the current price of hog fuel. When credits are given for achievement of other land management objectives additional sites can be economically processed. The greatest opportunities exist where residue recovery is a planned part of the harvest and sawlog recovery is conducted with this in mind. Economical residue recovery operations on a wide-spread basis will require a steady, reliable market for hog fuel in combination with credits for site improvement, slash disposal, and hazard abatement. Additional study is warranted in areas where slash disposal requirements can contribute to the delivery of the wood residue to an access point. The dozer piling study falls into this category.

Equipment specifically designed for the variation in piece size found in forest residues are in the early stages of development. Experience with these systems will point the way to equipment improvements. Additional innovation in residue recovery equipment is lacking because of the lack of solid, reliable markets for the material. Mill residues in the Intermountain region can supply the current demand for hog fuel. As demand increases and wood residue price increases, the shift to wood residues will take place and economical recovery systems will emerge. Results of the studies just discussed indicate that residue can currently be processed with some degree of efficiency using conventional logging equipment. The flow of wood through the system must often be altered, however, to accommodate the increase in wood volume and increased variety in piece size that exist when residue recovery is added to a conventional harvest operation. Efficient methods of using existing equipment to handle residue are still needed since conventional equipment will probably be part of any new system developed for residue recovery.

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Table 1: Total and effective hourly costs of equipment used in residue recovery studies.

Equipment Description	Original Cost	Life	Salvage Value	Hourly Rates: Fixed Cost	Hourly Rates: Operating Cost	Hourly Rates: Labor Cost	Sum	Effective Hourly Cost: Percent Effectiveness[1]	Effective Hourly Cost: Effective $/Hour[2]
Kludt Yarder	75,000	5	30,000	16.76	17.87	40.95	75.58	62[3]	68.79
Christy Yarder	45,000	5	18,320	10.50	9.68	40.95	61.13	71[3]	58.32
Clark 666 Cable Skidder	85,000	5	17,000	22.83	10.29	13.65	46.77	71[3]	43.79
Garrett 30A Cable Skidder	32,000	5	6,400	7.90	15.66	13.65	37.21	89	35.49
John Deere 440C Cable Skidder	52,000	5	10,400	12.82	9.24	13.65	35.71	50	31.09
International S8-B Grapple Skidder	92,500	5	40,000	20.37	11.14	13.65	45.16	85[3]	43.49
Clark 667 Grapple Skidder	92,500	5	40,000	20.37	12.00	13.65	51.02	70	42.42
Caterpillar 518 Grapple Skidder	104,000	5	30,800	25.66	17.42	13.65	56.73	75[3]	52.38
Case DH4 Mini-Skidder	33,020	5	5,000	5.95	3.27	7.80	17.02	74	16.17
International TD 15 Crawler with Grapple	150,000	5	75,000	32.50	27.82	13.65	73.97	88	70.63
Cat D-4 Tractor	95,000	5	47,500	22.47	11.79	13.65			
Cat D-5 Tractor	130,000	5	65,000	30.76	15.66	13.65			
Cat D-6 Tractor	156,000	5	78,000	36.92	18.75	13.65			
John Deere Model 450 Crawler	130,000	5	65,000	30.76	14.31	13.65	58.72	91	57.39
Cat 966B Front End Loader	194,000	5	97,000	45.92	14.94	13.65	74.51	48	66.74
John Deere 644C Front End Loader	120,000	5	24,000	32.24	10.77	13.65	56.66	58	52.14
Michigan 55 Front Loader	85,000	5	17,000	20.89	9.75	13.65	44.29	79	42.24
Prentice Loader # 100								71	35.00[4]
FMC 2800 Linkbelt Loader	180,000	5	36,000	35.39	24.67	13.65	73.71	57[3]	63.10
Nicholson Fuel Wood Processor	275,000	5	55,000	73.89	69.13	13.65	156.67	30	108.28
Trelan Model 14C Chipper	60,000	5	12,000	14.80	17.66	13.65	46.11	22	32.34
Morbark Model 22 Chiparvester with Morlift 1000 Knuckleboom	228,000	5	46,500	56.24	62.70	13.65	132.59	56[3]	105.00
Morbark Model 750 Chiparvester with Sliding Boom	214,000	5	42,800	42.07	48.80	13.65	104.52	32	71.34
Morbark Model 550 Chiparvester	135,000	5	27,000	33.30	40.64	13.65	87.59	29[3]	58.74
Sumner Hog (Vinson)								36[3]	
Fling Demolisher								53	
Hahn Harvester Full Tree Delimber	186,000	5	93,000	40.83	18.41	27.30	86.54	76[3]	82.12
CPTPA Shear	24,005	10	0	7.93	9.23	27.30	44.60	54[3]	26.20
FMC 200 LG Dumploader	177,000	5	35,400	43.66	57.38	13.65	114.69	75	100.35
FMC 200 BG Dumploader	192,000	5	38,400	47.36	60.68	13.65	121.69	81	110.16
Chevy Dump Truck (gas)	24,000	5	4,800	7.08	7.68	13.65	28.41	*	
Kludt Dump Truck									35.00[4]

[1] Percent of time machine running, includes working delays

[2] $/hour = fixed cost + labor cost + (operating cost × percent effectiveness)

[3] Average for all study units

[4] Based on contract price

Table 2: Effective hourly costs on specific study sites.

Study Module	Specific Study Site	Percent Effectiveness	Effective $/Hour
Kludt Yarder	Seed tree 1	46	65.93
	Seed tree 2	54	67.36
	Clearcut	72	70.58
	Shelterwood	74	70.93
Christy Yarder	Shelterwood	80	59.19
	Clearcut 1	72	58.32
	Clearcut 2	60	57.26
Clark Cable Skidder	Shelterwood	70	43.68
	Clearcut 1	71	43.79
	Clearcut 2	73	43.99
	Morbark 550	50	41.62
Cat 518	With Morbark 550	37	47.76
	With Morbark 22:Southwick	79	53.07
Cat 518 Grapple Skidder	Hahn Harvester	91	55.61
Hahn Harvester	With Chipper	74	81.65
	Without Chipper (one operator)	79	69.02
Morbark 22 with Morlift 1000	With Hahn:Chewelah	42	96.22
	Whole Tree:Southwick	78	118.80
	Dozer Piles:Emida	48	99.99
Morbark 550	Residue:First Entry	23	56.30
	Residue:Grapple Skidder	32	59.95
	Whole Tree:Morris	33	60.36
Vinson Hog	Lower Granite Dam	42	
	Kamiah	31	
International S8 Skidder	Mini Skidder	78	42.71
	Emida Dozerpiles	92	44.27
CPTPA Shear	Whiskey Creek	72	27.06
	Roadside	46	25.76
	Best Corner	72	27.37
	Orofino Creek	16	22.85
	Coeur d'Alene Mill	64	28.00
Prentice Loader	Whiskey Creek	49	17.15
	Roadside	94	32.90
	Best Corner	49	17.15
	Orofino Creek	86	30.10
	Coeur d'Alene Mill	44	15.40
FMC Link Belt Loader	Mt. Hood	53	62.11
	Timothy Lake	61	64.10

Table 3: Summary of production of slash and sawlogs on Kludt shelterwood and clearcut.

Production: Kludt shelterwood
Acreage: 4.6 acres
Number of turns: 948 (2.86 pieces/turn)

	Slash	Sawlogs	Total
Pieces	2026	686	2712
% by piece	75	25	100
Volume - ft^3	10282	10503	20785
% by volume	49	51	100
Weight - green tons (@50 lb/ft^3)	257.1	262.6	519.7

Production: Kludt clearcut
Acreage: 4.9 acres
Number of turns: 1100 (2.77 pieces/turn)

	Slash	Sawlogs	Total
Pieces	1927	1122	3049
% by piece	63	37	100
Volume - ft^3	13934	19084	33018
% by volume	42	58	100
Weight - green tons (@50 lb/ft^3)	348.4	477.1	825.5

Table 4: Summary of productive time and cost of yarding on Kludt shelterwood unit.

Production/time on Kludt yarding: shelterwood

	Percent of Total time	Cumulative Hours	Pieces per Hour	Ft^3 per Hour	Green ton Per hour
* Yarding elements	75	45.0	60.3	462	11.6
** Set up time	6	48.8	55.6	426	10.7
Carriage hooking problems	3	50.3	53.9	413	10.3
Maintenance/ breakdown	5	53.6	50.6	388	9.7
Hang-ups on hook/unhook	2	55.1	49.2	377	9.4
Interference/wait - other equip.	4	57.7	47.0	360	9.0
*** Other	4	60.3	45.0	345	8.6

YARDING COSTS

Percent effectiveness	$/Piece	$/$Ft^3$	$/Green ton
* 100	1.14	.15	5.93
** 94	1.24	.16	6.43
*** 75	1.53	.20	8.00

Table 5: Summary of productive time and cost of yarding on Kludt clearcut unit.

Production/time on Kludt yarding: clearcut

	Percent of Total time	Cumulative Hours	Pieces per Hour	Ft^3 per Hour	Green ton Per hour
* Yarding elements	72	51.4	58.1	642	15.7
** Set up time	7	56.7	52.7	582	14.3
Carriage hooking problems	2	58.0	51.5	569	14.0
Maintenance/ breakdown	9	64.4	46.4	513	12.6
Hang-ups on hook/unhook	3	66.2	45.1	499	12.2
Interference/wait - other equip.	6	70.8	42.2	466	11.4
*** Other	1	71.6	41.7	461	11.3

YARDING COSTS

Percent effectiveness	$/Piece	$/Ft^3$	$/Green ton
* 100	1.18	.11	4.38
** 93	1.31	.12	4.81
*** 72	1.65	.15	6.09

Table 6: Summary of production of slash and sawlogs on Christy shelterwood and clearcut.

Production: Christy yarding on shelterwood unit
Acreage: 3.40 acres
Number of turns: 367 (1.90 pieces/turn)

	Slash	Sawlogs	Total
Pieces	347	349	696
% by piece	50	50	100
Volume - ft^3	1481	10024	11505
% by volume	13	87	100
Weight - green tons (@50 lb/ft^3)	37.04	250.60	287.63

Production: Christy yarding on clearcut units
Acreage: 1.37 acres
Number of turns: 220 (1.73 pieces/turn)

	Slash	Sawlogs	Total
Pieces	89	291	380
% by piece	23	77	100
Volume - ft^3	431	10551	10982
% by volume	2	98	100
Weight - green tons (@50 lb/ft^3)	10.79	263.76	274.35

Table 7: Summary of production of slash and sawlogs after swing skidding and bucking on Christy shelterwood and clearcut.

Production: Christy swing skidding on shelterwood unit
Acreage: 3.40 acres (308 feet skid distance)
Number of turns: 208 (3.35 yarded pieces/turn)

	Slash	Sawlogs	Total
Bucked pieces	665	676	1341
% by piece	50	50	100
Volume - ft^3	5348	7452	12800
% by volume	42	58	100
Weight - green tons (@50 lb/ft^3)	133.71	186.29	320.00

Production: Christy swing skidding on clearcut units
Acreage: 1.37 acres (375 feet skid distance)
Number of turns: 141 (2.57 yarded pieces/turn)

	Slash	Sawlogs	Total
Bucked pieces	277	583	860
% by piece	32	68	100
Volume - ft^3	1502	8540	10042
% by volume	15	85	100
Weight - green tons (@50 lb/ft^3)	37.54	213.51	251.05

Table 8: Summary of productive time and cost of yarding on Christy shelterwood unit.

Production/time on Christy yarding: shelterwood

	Percent of Total time	Cumulative Hours	Pieces per Hour	Ft^3 per Hour	Green ton Per hour
* Yarding elements	55	22.88	30.4	503	12.6
** Set up time	20	31.28	22.3	368	9.2
Carriage hooking problems	2	32.28	21.6	356	8.9
Maintenance/ breakdown	7	35.10	19.8	328	8.2
Hang-ups on hook/unhook	3	36.47	19.1	315	7.9
Interference/wait - other equip.	5	38.54	18.1	299	7.5
*** Other	7	41.47	16.8	277	6.9

YARDING COSTS

Percent effectiveness	$/Piece	$/$Ft^3$	$/Green ton
* 100	1.92	.12	4.63
** 80	2.62	.16	6.34
*** 55	3.47	.21	8.45

Table 9: Summary of productive time and cost of swing skidding on Christy shelterwood unit.

Production/time of Christy swing skidding: shelterwood

	Percent of Total time	Cumulative Hours	Pieces per Hour	Ft^3 per Hour	Green ton Per hour
* Skidding cycle	32	18.28	38.1	700	17.5
Pile sawlogs	15	26.95	25.8	475	11.9
Pile slash	11	33.30	20.9	384	9.6
** Working delay	10	38.66	18.0	331	8.3
Wait on other ops. at landing	10	44.21	15.7	290	7.2
Interference/wait - other equip. at yarder	3	45.70	15.2	280	7.0
*** Other	19	56.35	12.4	227	5.7

SKIDDING COSTS

Percent effectiveness	$/Piece	$/Ft^3$	$/Green ton
* 100	.81	.04	1.77
** 64	1.72	.09	3.74
*** 32	2.50	.14	5.44

Table 10: Summary of productive time and cost of yarding on Christy clearcut unit.

Production/time on Christy yarding: clearcut

	Percent of Total time	Cumulative Hours	Pieces per Hour	Ft^3 per Hour	Green ton Per hour
* Yarding elements	51	8.65	43.9	1270	31.7
** Set up time	11	10.52	36.1	1094	26.1
Carriage hooking problems	1	10.75	35.3	1022	22.5
Maintenance/ breakdown	1	10.95	34.7	1003	25.1
Hang-ups on hook/unhook	4	11.57	32.8	949	23.7
Interference/wait - other equip.	20	14.91	25.5	737	18.4
*** Other	13	17.11	22.2	642	16.0

YARDING COSTS

Percent effectiveness	$/Piece	$/Ft^3	$/Green ton
* 100	1.33	.05	1.84
** 89	1.62	.05	2.23
*** 53	2.63	.09	3.65

Table 11: Summary of productive time and cost of swing skidding on Christy clearcut unit.

Production/time of Christy swing skidding: clearcut

	Percent of Total time	Cumulative Hours	Pieces per Hour	Ft³ per Hour	Green ton Per hour
* Skidding cycle	34	8.42	102.1	1193	29.8
Pile sawlogs	18	12.88	66.8	780	19.5
Pile slash	7	14.58	59.0	689	17.2
** Working delay	10	17.17	50.1	585	14.6
Wait for other ops. at landing	9	19.29	44.6	521	13.0
Interference/wait - other equip. at yarder	1	19.56	44.0	513	12.8
*** Other	21	24.89	34.6	403	10.1

SKIDDING COSTS

Percent effectiveness	$/Piece	$/Ft³	$/Green ton
* 100	.43	.04	1.47
** 65	.87	.07	3.00
*** 34	1.27	.11	4.33

Table 12: Total cost of delivery of biomass material through the landing on steep slopes.

	KLUDT STUDY		CHRISTY STUDY	
	Clearcut	Shelterwood	Clearcut	Shelterwood
TOTAL COST				
Yarding	$4925	$4148	$ 998	$2419
Shuttle	2506	2111	1090	2468
Loading	—	—	394	459
Bucking	967	814	336	761
Total	$8398	$7073	$2818	$6107
TOTAL COST FOR PRODUCTION OF BOTH SAWLOGS AND SLASH				
$/Piece	2.75	2.60	7.42	8.77
$/Ft^3	.25	.34	.26	.53
$/Green Ton	10.17	13.61	10.27	21,23
ALLOCATED COST PER PIECE FOR DELIVERY OF SLASH*				
Yarding	$1.61	$1.53	$2.62	$3.48
Shuttle	1.30	2.38	2.87	3.55
Loading	—	—	.68	.68
Bucking	.32	.30	.39	.57
Total	$3.23	$4.21	$6.56	$8.28
ALLOCATED COST PER GREEN TON FOR DELIVERY OF SLASH**				
Yarding	$8.91	$12.10	$6.11	$9.05
Shuttle	7.19	8.21	6.68	9.23
Loading	—	—	2.41	1.72
Bucking	1.75	2.38	2.06	2.85
Total	$17.85	$22.69	$17.26	$22.85
SLASH DISPOSAL COST IN DOLLARS PER ACRE***				
	$633	$676	$168	$356
% Slash pieces	63	75	23	50

*Calculated as (total cost x percent slash pieces)/slash pieces
**Calculated as (total cost x percent slash pieces)/slash weight
***Calculated as (yarding cost x percent slash pieces)/acres

Table 13: Summary of experienced costs from recovery of dozer piled slash

DOZER PILING COST

	RESIDUE RECOVERY		CONVENTIONAL	
Volume piled	761 cu ft/acre		413 cu ft/acre	
Area	5.84 acres		5.66 acres	
Average Dozing Distance	47 feet		36 feet	
	Productive Hours	Scheduled Hours	Productive Hours	Scheduled Hours
TOTAL COST: PILING	$403.58	$426.51	$463.69	$496.90
Dollars per acre	69.11	73.03	81.92	87.79
Dollars per cu ft	.091	.096	.198	.213

RESIDUE RECOVERY COSTS

	LONG SKID		SHORT SKID[3]	
Average Skid Distance	446 feet		162 feet	
	Productive Hours[1]	Scheduled Hours[2]	Productive Hours[1]	Scheduled Hours[4]
SKIDDING				
Dollars per van	174.88	201.15	n.a.	n.a.
Dollars per green ton[5]	7.96	9.00	4.80	5.06
Dollars per cubic foot	.143	.162	.086	.091
CHIPPING				
Dollars per van	96.78	268.10	n.a.	n.a.
Dollars per green ton[5]	4.40	12.18	4.40	5.65
Dollars per cubic foot	.079	.219	.079	.102
COST OF SKIDDING AND CHIPPING				
Dollars per van	271.66	469.25	n.a.	n.a.
Dollars per green ton[5]	12.36	21.18	9.20	10.71
Dollars per cubic foot	.222	.381	.165	.193

[1] Based on dollar per hour cost of 45.16 for skidder and 87.59 for chipper
[2] Based on effective dollar per hour cost of 43.51 for skidder and 56.30 for chipper
[3] Based on chip pile volume estimation of 625.84 cubic feet
[4] Based on dollar per hour cost of 44.42 for skidder and 60.77 for chipper
[5] At 36 lb./cu.ft. for field dried material

Table 14: Summary of Experienced Costs for Recovery of Slash With Modified FMC Units.

UNIT: Lostine 17
Mt. Hood National Forest

Area: 12 acres
Volume Removed: 17,334 cu ft[1]
Average Skid Distance: 605 ft.

MACHINE	FMCBG	FMC 200	Sum or Average
Capacity (ft^3)	500	257	757
Turns	44	18	62
Productive time (hours)	10.91	3.70	14.61
Time with necessary delays (hours)	13.41	4.33	17.73
Scheduled time (hours)	19.93	9.91	29.84
Percent effectiveness	55	37	–
Effective hourly rate	$110.16	$100.35	–
with necessary delays	$113.36	$100.79	–
Total hourly rate	$121.69	$114.69	–
TOTAL VOLUME REMOVED	14,325 ft^3	3,009 ft^3	17,334 ft^3 [1]
HOURLY PRODUCTION			
Productive hour	1,313 ft^3/hr	813 ft^3/hr	1,186 ft^3/hr
With necessary delays	1,068 ft^3/hr	694 ft^3/hr	978 ft^3/hr
Scheduled hour	719 ft^3/hr	304 ft^3/hr	581 ft^3/hr
TURNS PER HOUR			
Productive hour	4.0	4.9	4.2
With necessary delays	3.3	4.2	3.5
Scheduled hour	2.2	1.8	2.1
TOTAL COST			
Productive hours	$ 1,327.64	$ 424.35	$ 1,751.99
With necessary delays	1,520.16	436.42	1,956.58
Scheduled hours	2,195.49	994.47	3,189.96
DOLLARS PER TURN			
Productive hours	$ 30.17	$ 23.58	$ 28 26
With necessary delays	34.55	24.25	31.56
Scheduled hours	49.90	55.25	51.45
DOLLARS PER CU FT			
Productive hours	$ .093	$ .141	$ .101
With necessary delays	.106	.145	.113
Scheduled hours	.153	.330	.184

[1] based on net of down and dead inventories before and after operations
[2] necessary delays include waiting, moving to next slash pile, positioning grapple after loading, and other delays that were part of the normal work cycle
[3] effective hourly rate of $121.69/hr on FMCBG and $114.69/hr on FMC 200.
[4] effective hourly rate of $113.36/hr on FMCBG and $100.79/hr on FMC 200.
[5] effective hourly rate of $110.16/hr on FMCBG and $100.35/hr on FMC 200.

Table 15: Total cost of delivery of residue including the cost of loader.

	FMCBG	FMC 200
LOADER COSTS PER CU FT[1]		
Productive hours	.048	.078
With necessary delays	.060	.090
Scheduled hours	.088	.208
TOTAL COST IN DOLLARS PER CU FT INCLUDING LOADER		
Productive hours	.141	.219
With necessary delays	.166	.235
Scheduled hours	.241	.538
TOTAL COST IN DOLLARS PER GREEN TON INCLUDING LOADER[2]		
Productive hours	7.83	12.17
With necessary delays	9.22	13.06
Scheduled hours	13.38	29.89

[1] Effective hourly rate of $63.10/hr for FMC 2800 linkbelt
[2] At 36 lb./cu. ft. for field dried material

Table 16: Comparison of Chipping of Residue from Hahn Harvester With Morbark Model 22 When All Limbs are Chipped and When Limbs Separated from Boles or Tops are Discarded.

TYPE MATERIAL CHIPPED PER VAN

	Grapple Loads	Butts	%	Limbs	%	Tops	%	Logs	%	Whole Trees	%	Green Tons
WITH LIMBS												
TOTAL	473	32	2.1	884	58.7	458	30.4	72	4.8	61	4.0	60.5
AVG	157.7	10.7	–	294.7	–	152.7	–	24.0	–	20.3	–	20.2
WITHOUT LIMBS												
TOTAL	1,068	70	3.6	207	10.5	1,112	56.6	154	7.8	42.1	21.4	131.7
AVG	152.6	10	–	29.6	–	158.9	–	22	–	60.1	–	18.8

TIME/PRODUCTION PER VAN

	Green Tons	Grapple Loads	Productive Time (min)	Mean Time Per Grapple Load	Scheduled Time(min)	Green Tons Per Productive Hour	Green Tons Per Scheduled Hour
WITH LIMBS							
TOTAL	60.5	473	162.7	–	678.9	–	–
MEAN	20.2	157.7	54.2	.342	226.3	22.31	5.35
STD DEV	.72	23.8	10.8	.016	170.0	4.70	3.97
WITHOUT LIMBS							
TOTAL	131.7	1,068	371.1	–	1,398.4	–	–
MEAN	18.8	152.6	53.0	.347	199.8	21.29	5.65
STD DEV	2.48	24.0	8.91	.016	40.9	2.78	1.56

Table 17: Comparison of chipping time and production rates for Morbark Model 22 chipping residue from Hahn Harvester when all limbs are chipped and when limbs separated from boles or tops are discarded.

	With limbs	Without limbs
Green tons per van	20.2	18.8
Percent of pieces as limbs	58.7	10.5
Productive time per van (min)	54.2	53.0
Scheduled time per van (min)	226.3	199.8
Percent productive	24	27
Green tons/productive hour	22.31	21.29
Green tons/scheduled hour	5.35	5.65

Table 18: Comparison of Production Rates for Skidding and Tree Processing With a Hahn Harvester With and Without Adjacent Chipping.

			PIECES/HOUR		CUBIC FEET/HOUR	
UNIT	MACHINE	% EFFECTIVENESS	BY PRODUCTIVE HOURS	BY SCHEDULED HOURS	BY PRODUCTIVE HOURS	BY SCHEDULED HOURS
WITH CHIPPING	Hahn	74	162.5	119.4	1,993.65	1,465.29
	Rubber Tired Skidder (CAT 518)	96	78.9	75.2	1,298.18	954.13
	Crawler Tractor (TD-15)	89	52.8	46.7	518.39	494.04
WITHOUT CHIPPING	Hahn	79	106.7	83.8	1,415.41	1,111.49
	Rubber Tired Skidder (CAT 518)	87	121.3	105.5	1,609.16	1,399.97
	Crawler Tractor[1] (TD-15)					

[1] Crawler Tractor did not skid, but it did built landings and pile slash for 1.9 hours.

Table 19: Comparisons of Cost of Skidding and Tree Processing With Hahn Harvester With and Without Adjacent Chipping.

MACHINE	HOURLY COST EFFECTIVE TOTAL	DOLLARS/PIECE		DOLLARS/CUBIC FOOT	
		BY PRODUCTIVE HOUR	BY SCHEDULED HOUR	BY PRODUCTIVE HOUR	BY SCHEDULED HOUR
			WITH ADJACENT CHIPPING		
Hahn	81.65 (86.54)	.53	.68	.04	.06
Rubber Tired Skidder (CAT 518)	55.86 (56.73)	.72	.74	.04	.06
Crawler Tractor (TD-15)	70.63 (73.97)	1.40	1.51	.14	.14
TOTAL		2.65	2.93	.22	.26
			WITHOUT ADJACENT CHIPPING[1]		
Hahn	69.02 (72.89)	.68	.82	.05	.06
Rubber Tired Skidder (CAT 518)	54.47 (56.73)	.47	.52	.04	.04
Crawler Tractor (TD-15)	73.97	—	.06	—	.01
TOTAL		1.15	1.40	.09	.11

[1] Price reflects the use of only one operator.

Table 20: Comparison of Hahn Harvester Productive and Foreign Element Time With and Without Adjacent Chipping.

	SITE 1				SITE 2	
	WITHOUT CHIPPING		WITH CHIPPING		WITHOUT CHIPPING	
PRODUCTIVE TIME	Mean Time/ Occurrence	Percent of Total Time	Mean Time/ Occurrence	Percent of Total Time	Mean Time/ Occurrence	Percent of Total Time
First piece						
Load	.306	24.5	.298	23.0	.377	29.6
Limb	.168	13.3	.187	14.4	.179	14.0
Buck	.179	14.3	.177	13.6	.063	4.9
SUBTOTAL	–	52.1	–	51.0	–	48.5
SECOND AND SUBSEQUENT PIECES						
Load	.076	1.2	.061	1.5	.126	4.0
Limb	.131	2.1	.141	3.4	.218	6.9
Buck	.140	2.3	.154	3.7	.059	1.9
SUBTOTAL	–	5.6	–	8.6	–	12.8
WORKING DELAYS						
Realign tree on bed	–	–	.130	.3	.917	.9
Buck butt of tree	.186	2.9	.172	2.3	.218	1.8
Deck tree	.420	1.2	1.495	4.1	2.563	.6
Deck logs	.325	.2	.371	.5	2.650	.3
Remove slash from bed	.746	3.6	.501	3.4	.676	1.3
Log hung up	1.430	.4	.473	.5	.482	.3
Remove slash with loader	.933	6.8	.527	2.7	1.251	12.3
Sorting with loader	.790	2.0	.272	.6	–	–
SUBTOTAL	–	17.0	–	14.4	–	17.5
DELAYS OTHER OPERATIONS						
Moving	–	–	–	–	9.680	2.3
Skidder delays	2.460	1.4	3.550	1.5	–	–
Wait for tree	2.841	8.0	3.501	13.1	2.829	3.6
SUBTOTAL	–	9.4	–	14.6	–	5.9
NONPRODUCTIVE DELAYS						
Personal	2.584	3.6	3.063	4.0	1.253	1.1
Mechanical breakdown	18.550	10.4	16.573	5.8	17.075	4.1
Maintenance	2.090	1.8	1.864	.5	5.484	3.3
Other	.240	.1	.622	1.1	11.372	6.8
SUBTOTAL	–	15.9	–	11.4	–	15.3
TOTAL DELAY	–	42.3	–	40.4	–	38.7
TOTAL PRODUCTIVE	–	57.7 100.0	–	59.6	–	61.3 100.0

Table 21: Comparison of Skidding Decking Production and Foreign Elements of Cat 518 Grapple Skidder Delivering Material and Clearing Landing for a Hahn Harvester With and Without Adjacent Chipping.

	WITH CHIPPING		WITHOUT CHIPPING	
	Mean Time/ Occurrences	Percent of Total Time	Mean Time/ Occurrences	Percent of Total Time
PRODUCTIVE TIME				
Skid time	7.84	81.2	2.87	49.2
Deck trees	1.52	11.7	.64	10.2
WORKING DELAYS				
Deck logs	.07	1.0	4.22	5.8
Clear landing:				
Pile limbs and tops	2.98	2.2	2.05	19.1
Haul slash with grapple	.58	.1	–	–
Clean debris	4.93	.2	–	–
SUBTOTAL	1.07	2.4	2.32	24.8
DELAY OTHER OPERATIONS				
Wait for Hahn	–	–	1.87	6.9
Landing plugged	2.95	.1	–	–
Wait for other operations	–	–	12.81	2.9
Skidder in way	1.74	.2	–	–
Moving	–	–	18.41	2.8
SUBTOTAL	2.04	.3	3.09	12.6
NONPRODUCTIVE DELAYS				
Personal	–	–	1.28	1.1
Mechanical breakdown	33.41	2.1	–	–
Maintenance	4.32	.1	2.22	3.2
SUBTOTAL	9.67	4.5	2.92	4.3
TOTAL DELAY	2.52	7.1	2.51	40.7
TOTAL PRODUCTIVE	8.97	92.9	3.47	59.3
TOTAL SCHEDULED	–	100.0	–	100.0

Table 22: Comparison of Skidding Time and Costs for Delivery of Material to a Hahn Harvester Working With and Without an Adjacent Chipper. Skidding Turn Times Were Adjusted to the Distances Skidded at One Site.

	ADJUSTED TURN TIMES		
TIME IN MIN	WITH CHIPPING	WITHOUT CHIPPING	
Base Skidding[1] Time	7.84		7.84
Non Skidding[2] Work Time	1.45		2.04
Other Delay Time	.46		.99
Total Turn Time	9.29		9.88
Dollars/Turn[3]	$8.78/turn		$9.34/turn
Pieces/Turn	7.2		5.8
Cubic Feet/Turn	210.8		136.3
COST			
Dollars/Piece	1.22	1.51[4]	1.61
Dollars/Cubic Foot	.042	.064	.069
Dollars/Green Ton[5]	1.67	2.58	2.74

[1] Base time equated to that of non-chipping operation
[2] Time for elements such as clearing the landing of limbs and tops
[3] At $56.73/hour for skidder and operator
[4] At without chipping production of 5.8 pieces per turn and with chipping turn time
[5] At 50 lb./cubic foot

Table 23: Analysis of Time Elemental Costs Per Tree of Hahn Harvester That Could be Affected by Presence of Whole Tree Chipper.

LOCATION	SITE 1				SITE 2	
	WITHOUT CHIPPING		WITH CHIPPING		WITHOUT CHIPPING	
NUMBER OF TREES	284		2419		1305	
	Total Time in Min	Min Per Tree	Total Time in Min	Min Per Tree	Total Time in Min	Min Per Tree
ELEMENT						
Deck trees	4.20	.0148	128.50	.0531	10.25	.0079
Deck logs	.65	.0023	15.21	.0063	5.30	.0041
Remove slash from bed	12.68	.0446	107.70	.0445	20.96	.0161
Remove slash with loader	24.47	.0855	84.28	.0348	203.90	.1562
Sort trees with loader	7.11	.0250	17.12	.0071	—	—
SUBTOTAL	48.91	.1722	352.80	.1458	240.36	.1841
COST IN $/TREE[1]		.25		.21		.27
TOTAL PRODUCTIVE AND WORKING TIME	265.4	.93	2,321.3	.96	1,310.3	1.00
COST IN $/TREE[1]		1.34		1.38		1.44 1.21[2]
TOTAL SCHEDULED TIME	355.0	1.25	3,144.7	1.30	1,657.4	1.27
COST IN $/TREE[1]		1.80		1.88		1.84 1.54[2]

[1] At $86.54/hour with 2 operators on Hahn Harvester
[2] At $72.89/hour with 1 operator on Hahn Harvester

Table 24: Summary of Chipping Production and Delays for a Variety of Whole Tree Chippers and Slash Processes While Processing both Whole Trees and Residue Material

Type Chipper	Setting	Percent Productive	Time/Van (Min)		Green Tons/Hour		Load Weight	Comment
			Productive	Scheduled	Productive	Scheduled		
Trelan 14 (120 HP)	Tops	22	45.3 (small van)	212.6	17.1	3.7	25,900	38%-wait material 21%-skidder interference
Morbark 550 (300 HP)	Whole Tree	32	50.1	157.1	32.1	11.1	51,900	25%-wait material
	Slash deck (well formed)	30	45.7	157.5	20.1	5.8	30,600	12%-wait material 12%-change vans 14%-breakdown skidder-63% wait chipper
	Slash deck (poor skidder)	21	55.6	282.2	19.1	4.6	35,100	19%-wait material 23%-maintenance 10%-wait van
Morbark 22 (300 HP)	Whole Tree	30	31.7	106.6	46.6	13.7	48,800	56%-wait van 8%-wait material
	Dozer piles	29	66.3	230.2	19.9	5.7	43,900	43%-wait material
	Hahn harvester slash[1]	27	53.4	207.7	21.7	6.0	38,400	33%-wait material 10%-sort
Morbark 750 (600 HP)	Whole Tree	27	20.2	73.7	76.1	32.6	49,600	41%-wait van
Nicholsen	Landing slash (poor, rocks)	30	54.1	179.8	25.1	9.4	44,000	27%-maintenance 9%-wait material
	Landing slash	31	51.5	165.0	41.6	17.5	48,700	20%-wait van 23%-move
Vinson Hog	Mill slash	31	53.8	174.5	22.6	7.8	36,600	17%-wait material 23%-knife maintenance
	Reservoir debris	41	68.8	169.3	21.3	9.9	47,700	17%-wait van
CPTPA Shear	Landing slash[2]	56	39.0 (small truck)	69.2	10.1	5.7	12,800	

[1] Includes chip time into stock pile in addition to vans
[2] For Coeur d'Alene mill unit - 13 truck loads

Table 25: Detailed Van Averages for Whole Tree Chippers and Residue Processors

	Setting/Material	Number of Vans	Green Tons Per Productive Hour Mean	Green Tons Per Productive Hour Std. Deviation	Green Tons Per Scheduled Hour Mean	Green Tons Per Scheduled Hour Std. Deviation	Load Weight lbs. Mean	Load Weight lbs. Std. Deviation
Trelan 14 (120 HP)	Tops	1.3	16.90		3.64		26,400	
Morbark 550 (300 HP)	Whole Tree	8	32.08	7.55	11.05	3.94	51,900	6,954
	Slash Deck (well formed)	4[1]	19.73	3.01	7.48	1.98	30,600	1,706
	Slash Deck (poor skidder)	6	19.10	2.63	4.56	1.62	35,100	2,575
Morbark 22 (300 HP)	Whole Tree[2]	16	46.61	10.64	32.85	7.00[2]	48,800	2,831
	Dozer Piles	1	19.90		5.73		43,900	
	Hahn Harvester Slash	10	21.96	3.24	6.33	2.37	38,400	4,320
Morbark 750 (600 HP)	Whole Tree	22	76.05	13.30	32.61	18.33	49,600	1,937
Nicholsen Fuel Wood Processor	Landing Slash (poor with rocks)	5	41.62	21.90	17.54	13.47	48,700	1,768
	Landing Slash (fair condition)	5	25.09	5.64	9.37	5.95	44,000	3,843
Vinson Hog	Mill Slash	9	22.60	10.99	7.80	4.40	36,600	7,874
	Reservoir Debris	8	21.27	3.94	9.93	3.81	47,700	3,693
CPTPA	Landing Slash	27[3]	8.91	2.66	5.52	2.07	13,500	2,123

[1] 10.5 van loads were processed, weight available on 4, production per scheduled hour was higher on first 4 vans than on last 6.5 (Table 24)
[2] Based on scheduled time without chip van delays
[3] 36 truck loads were processed, weight available on 27

Table 26: Costs of Chipping and Processing Whole Trees and Slash Material

		Percent Productive	Effective $/Hour (Sum of $/Hour)	Cost in $/Van for Productive[1] Hours	Cost in $/Van for Scheduled[2] Hours	Cost in $/Green Ton for Productive[1] Hours	Cost in $/Green Ton for Scheduled[2] Hours
Trelan 14 (120 HP)	Tops	22	32.34 (46.11)	34.81	114.59	2.69	8.74
Morbark 550 (300 HP)	Whole Tree	32	60.36 (87.59)	73.14	158.04	2.73	5.44
	Slash Deck (well formed)	30	59.95 (87.59)	66.71	157.37	4.36	10.34
	Slash Deck (poor skidder)	21	56.30 (87.59)	81.17	264.80	4.59	12.24
Morbark 22[3] (300 HP)	Whole Tree	30	58.91 (87.59)	46.28	101.66	1.88	4.30
	Dozer Piles	29	56.30 (87.59)	96.49	216.00	4.30	9.88
	Hahn Harvester Slash	27	57.90 (87.59)	77.96	200.13	4.04	9.65
Morbark 750 (600 HP)	Whole Tree	27	71.34 (104.52)	35.19	87.63	1.37	2.19
Nicholsen Fuel Wood Processor	Landing Slash (poor, rocks)	30	108.28 (156.67)	111.26	324.48	6.24	11.52
	Landing Slash	31	108.28 (156.67)	134.48	297.77	3.77	6.19
Vinson Hog	Mill Slash	31	n.a.	n.a.	n.a.	n.a.	n.a.
	Reservoir Debris	41	n.a.	n.a.	n.a.	n.a.	n.a.
CPTPA Shear	Landing Slash	56	26.20 (44.60)	28.99	30.22	4.42	4.60

[1] based on sum of $/hour
[2] based on effective $/hour
[3] per hour cost of Morbark 22 set equal to that of Morbark 550. Model 22 currently available is higher priced, higher capacity machine.

Table 27: Production Rates for Skidders and Loaders Delivering Whole Trees and Slash to Processing Units.

Chipper	Delivery Unit	Percent Productive	Time/Van (Min) in Productive Time	Time/Van (Min) in Scheduled Time	Green Tons per Productive Hour	Green Tons per Scheduled Hour
Trelan 14 (120HP)	Garrett 30A Cable	89	318.0	355.6	2.4	2.2
Morbark 550 (300 HP)	Clark 668 Fixed Grapple Skidder	n.a.	n.a.	n.a.	n.a.	n.a.
	CAT 518 Swinging Grapple Skidder	27	46.5	174.4	19.8	5.3
Morbark 22 (300 HP)	Cat 518 Swinging Grapple Skidder	75	80.4	107.7	18.2	13.6
	International S-8 Swinging Grapple Skidder	87	248.1	285.2	6.6	5.7
Morbark 750 (600 HP)	Clark 667 Swinging Grapple Skidder	61	43.1	70.2	34.5	21.2
Nicholsen Fuel Wood Processor	FMC Link-Belt 2800 Hydraulic Loader	57	39.0	167.6	37.5	8.7
	John Deere 644-B Front-end Loader	41	64.4	157.7	20.5	8.4
Vinson Hog	Cat 966B Front-end Loader	44	79.9	181.3	13.8	6.1
CPTPA Shear	Prentice Model 100 Hydraulic Loader	48	32.3	66.9	12.2	5.9

Table 28: Cost of Delivering Whole Trees and Residue to Chipping and Processing Units

Chipper	Delivery Unit	\$/Hour (Sum of Hours)	Cost in \$/Van for Productive[1] Hours	Cost in \$/Van for Scheduled[2] Hours	Cost in \$/Green Ton for Productive[1] Hours	Cost in \$/Green Ton for Scheduled[2] Hours
Trelan 14 (120 HP)	Garrett 30A Cable Skidder	35.49 (37.21)	197.21	210.31	15.50	16.13
Morbark 550 (300 HP)	Clark 668 Fixed Grapple Skidder (whole tree)	41.62 (46.77)	39.05	108.98	1.16	3.75
	Clark 668 Fixed Grapple Skidder (slash)	41.62 (46.77)	43.34	195.75	2.45	9.05
	Cat 518 Swinging Grapple Skidder (slash)	43.95 (56.73)	43.97	127.74	2.87	8.29
Morbark 22 (300 HP)	Cat 518 Swinging Grapple Skidder	53.07 (56.73)	76.02	95.26	3.12	3.90
	International S 8 Swinging Grapple Skidder	43.49 (45.16)	186.74	206.72	6.84	7.63
Morbark 750 (600 HP)	Clark 667 Swinging Grapple Skidder	42.42 (51.02)	36.65	49.63	1.48	2.00
Nicholsen	FMC Link-Belt 2800 Hydraulic Loader	63.10 (73.71)	47.91	176.26	1.97	7.25
	John Deere 644 B Front-end Loader	52.11 (56.66)	60.81	137.04	2.76	6.21
Vinson Hog	Cat 966B Front-end Loader	66.74 (74.51)	99.22	201.67	5.40	10.94
CPTPA	Prentice Model 100 Hydraulic Loader	35.00[3]	18.84	39.02	2.89	5.93

[1] based on sum of \$/hour - operating cost
[2] based on effective \$/hour - includes productive time and working delays
[3] based on contract price

Table 29: Total Cost of Chipping and Processing Whole Trees and Slash Material as Observed Including the Cost of Delivery

Chipper	Setting	Delivery Unit	Cost in $/Van (Scheduled Hrs)	Cost in $/Green Ton (Scheduled Hrs)
Trelan 14 (120 HP)	Tops	Garrett 30A	324.93	24.87
Morbark 550 (300 HP)	Whole Tree	Clark 668	267.02	9.19
	Slash Deck (well formed)	Cat 518	285.11	18.63
	Slash Deck (poor delivery)	Clark 668	460.55	21.29
Morbark 22 (300 HP)	Whole Tree	Cat 518	199.92	8.20
	Dozer Piles	International S-8	422.72	17.51
	Slash	Hahn Harvester	200.43	9.65
Morbark 750 (600 HP)	Whole Tree	Clark 667	137.26	4.19
Nicholsen	Landing Slash (poor, rocks)	FMC Link-Belt 2800	500.74	18.77
	Landing Slash	FMC Link-Belt 2800[1] and John Deere 644B	457.56	13.00
Vinson Hog	Mill Slash	Cat 966B	n.a.	n.a.
CPTPA Shear	Landing Slash	Prentice 100[2]	69.24	10.53

[1] based on weighted average of both loaders (42% front end, 58% hydraulic)
[2] based on loader contract price

Table 30: Total cost of chipping and processing whole trees and slash material

Chipper	Setting	Chipping/delivery cost from cold deck in $/green ton for scheduled hours	Total cost of delivery to cold deck and chipping in $/green ton for scheduled hours
Trelan 14 (120 HP)	Tops	24.87	24.87
Morbark 550 (300 HP)	Whole Tree	9.19	9.19
	Slash Deck (well formed)	18.63	36.77[4]
Morbark 22 (300 HP)	Whole Tree	8.20	8.20
	Dozer	17.51	22.84[5]
	Slash	9.65[1]	9.65
Morbark 750 (600 HP)	Whole Tree	4.19	4.19
Nicholsen	Landing Slash (poor, rocks)	18.77	25.49[6]
	Landing Slash[2]	13.00	19.72[6]
Vinson Hog	Mill Slash	n.a.	n.a.
CPTPA Shear	Landing Slash[3]	10.53	10.53

[1] does not include skidding cost
[2] based on weighted average of both loaders
[3] based on loader contract price
[4] weighted average of Kludt cable yarder
[5] including dozer piling cost at $.096/cu.ft. and 36 lb./ft^3 for field dried slash
[6] including FMC BG delivery costs at $.121/cu.ft. and 36 lb./ft^3